[1.] **Precious EHIOMOGUE**

# VERMICOMPOST REMEDIATION OF CONTAMINATED SOIL: A MINI REVIEW

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**Abstract:** The remediation of contaminated soil via vermicomposting and the advantages of the remediation process were reviewed. The reviewed was aimed at presenting the vermicomposting process of remediating soils contaminated with heavy metals, organic matters and hydrocarbons. Vermicomposting have been beneficial in decontaminating aqueous media by adsorbing or degrading pollutants, increasing soil fertility and agricultural productivity and promoting the biocontrol of agricultural disease. This mini–review indicates that vermicomposting is a promising low–cost and environmentally friendly way of treating contaminated soils.
**Keywords:** vermicompost, remediation, earthworm, contaminated soil

## 1. INTRODUCTION

The soil have always been contaminated with huge volume of waste, heavy metals and oily sludge from the domestic and industrial production and processing of various materials. These contaminants are made up of deleterious components, hydrocarbons and heavy metals (Koolivandet *al.,* 2020). Organic contaminants, sludge and heavy metals are contributor to soil degradation which also affect human and animal heath as a result of their accumulation in food chain (Yoon *et al.,* 2006; Belliturket *al.,* 2015), as well as decrease the quality of the soil for crop growth and the activities of soil organisms (Sunithaet *al.,* 2014). Most heavy metals are deposited mainly on the soil where they exhibit their toxic effects on the soil which in turn affect several physiological plant processes (Jadia and Fulekar, 2008), as well disturb enzymatic process and increase plant predisposition to fungal invasion (Kabata–Pendias and Pendias, 2001).

Remediation of contaminated soil involves thorough treatment of the soil which may be physical, chemical or biological process. Several process have been utilized for soil remediation such as soil vapor extraction, freed product recovery, solvent extraction, incineration, activated carbon adsorption, aeration towers and bioreactors (Dores–Silva *et al.,* 2019). Nevertheless, majority of these remediation processes are associated with extended periods of exposure and high clean ups cost (Mohan *et al.,* 2006).Bioremediation processes such as vermicomposting are effective for remediating contaminated soil as they are economically viable (Mohammed and Abubakar, 2015) although they are limited by factors such as types of microorganism used, temperature, pH of the soil and bioavailability of the contaminants (Garcia–Sanchez *et al.,* 2018).

Natural humidification of the soil is a slow process which produces humic matter accelerated by composting organic residues (Pereira *et al.,* 2014). Composting is an environmental process used in recycling waste materials, destroying the pathogens in the waste, converting nitrogen into stable organic forms, decreasing the volume of the waste and improving the physicochemical characteristics of the residues (Pereira and Arruda, 2003). Contrary to composting, vermicomposting involves the use of earthworms for metabolizing organic debris by softening of the residues with the animal's saliva, neutralization of the calcium excreted from the inner walls of the animal's esophagus, grinding the residue particles in their muscular gizzard, digesting of the organic material by proteolytic enzymes present in their stomach and the decomposition of the mashed organic particles through the activities of enzymes such as amylases, proteases and lipases (Pereira and Arruda, 2003; Forneset *al.,* 2012). This biochemical process results to the excretion of vermicompost which when allowed for a period of six months, matured continuously, increasing the humid compound in order to achieve stabilization of the organic matter (Landgrafet *al.,* 1998; Pereira *et al.,* 2014).

Vermicomposting is a mesophilic transformation in which the resulting material is made up of structural properties that aid in facilitating aeration and retaining water (Bellturket *al.,* 2015), thus increasing the cation exchange capacity of the soils and enhancing the adsorption of positive ions (Herwijnenet *al.,* 2007). This remediation process enhances plant growth, aid in phytoremediation as well as immobilize metal pollutants (Bellturket *al.,* 2015). The earthworms which are bioaccumulators bioremediate the metal contents of the compost generated from the waste materials (Pattnaik and Reddy, 2012). The porous nature of vermicompost materials as shown in the Screening Electron Micrograph (SEM) (Figure 1) enhances the adsorptive characteristics of the process. The adsorptive potentials of the vermicomposting


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process is observed in the numerous hydrophilic groups (such as –OH, –COOH, –SH etc.) (Figure 2) present in the humidified material, the high surface area and the vast porosity of the material (Pereira *et al.,* 2014).

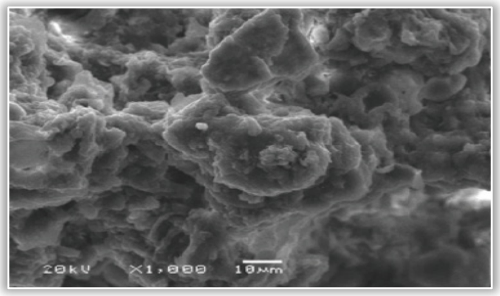


Figure 1: Electron micrograph of a vermicompost sample (Pereira *et al.,* 2014)

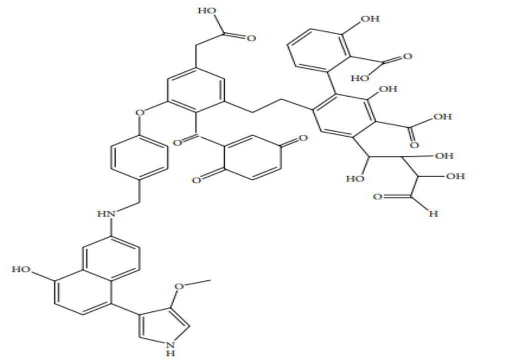

Figure 2: Structural fragment of a macroconstituent of vermicompost with numerouschemical groups (Vanloon and Duffy, 2005)

Owing to the fact that vermicomposting increases the humic acid content of the soil as well as emits lesser quantities of atmospheric pollutants, it is considered more beneficial than composting. According to Nagavallemma *et al.,* (2006), vermicompost accumulates higher levels of organic macro and micronutrients such as Carbon, Nitrogen, Phosphorus, Potassium, Calcium, Zinc, Magnesium, Sodium, Iron, Manganese and Copper. Also Busatoet *al.,* (2012) observed that these plant nutrients exhibit greater availability when vermicompost is applied to the soil. Thus, vermicomposting is considered an environmentally friendly amendment technique for contaminated soils and adopted by researchers for the treatment of contaminated soil. Liu *et al.,* (2019) observed in their studies that the adsorption of metals onto vermicompost and an increase in soil pH after the vermicompost amendment of the soil, are possibly responsible for the decreased availability of Cd, Ni, and Cr in the contaminated soil.

## 2. VERMICOMPOSTING PROCESS

Vermicomposting process which involves the breaking down of the waste matter (Dominguez, 2004) begins in the gizzard of earthworms where the waste is digested in the guts of the earthworm by enzymes and microorganisms (Grasserovaet *al.,* 2020). This process can result to the removal of pollutant from the soil thus known as vermiremediation (Rodriguez–Campos et al., 2014). According to Shi et al. (2019), vermicomposting is one of the vermiremediation processes which also include vermitransformation, vermiaccumulation, vermiextraction and drilodegradation. Several researchers have used these processes in the removal of micro–pollutants and heavy metals from the soil (Aziziet *al.* 2013; Sutharet *al.* 2014; Chachinaet *al.* 2016; He *et al.* 2016; Chevillotet *al.* 2017; Havraneket *al.* 2017; Roratet *al.* 2017; Lin *et al.* 2019; Owagboriaye *et al.* 2020). The earthworms present in the soil reduced the waste by grinding them into smaller particles thereby increasing the availability for microorganisms (Grasserovaet *al.,* 2020). Earthworms can also accumulate heavy metals such as cadmium and zinc in their soft tissue which they can transform into valent state making them less toxic and more available for plant. Studies have also shown that earthworm increases the activity of the detoxification of enzymes cytochrome P450 and glutathione–S–transferase by ingesting them into their tissues thereby degrading and detoxifying them (Achaziet *al.* 1998; Zhang *et al.* 2009; Zhao *et al.* 2020).

The physical and biochemical activities of the earthworm leads to the rapid ingestion and degradation of the waste matter within a shorter period of time into the tissues of the earthworm (Dores–Silva *et al.,* 2019) results to the creation of a high quality compost materials which are rich in essential elements required by plants such as phosphorus (P), nitrogen (N), sulfur (S), potassium (K) and magnesium (Mg) (Rodriguez–Campos *et al.,* 2014; Brinzaet *al.,* 2014). Nagavallemmaet *al.* (2006) in their study showed the accumulation of the macro and micronutrients; nitrogen, calcium, phosphorus, organic carbon, sodium, zinc, copper, iron, and manganese via vermicomposting. Owing to the increase in the humic acid content and emission of atmospheric pollutants during vermicomposting, it is considered more beneficial than other bioremediation processes (Pereira *et al.,* 2014). The process as exhibit greater availability of crop nutrient when used in soil remediation (Busatoet *al.,* 2012).

The study by Nagavallemmaet *al.* (2006) showed that vermicomposting is usually carried out in pits dug deep into the soil below the ground although most times vermicomposting on the soil surface has also be conducted successfully. The process can also be conducted in containers of tanks made up of several materials such as local rocks, hollow bricks, cement rings, among others (Pereira *et al.,* 2014). During


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vermicompost processing, the waste deposited on the soil is allowed to mix with earthworm. Different kinds of soils can also be added to the mixture thus enhancing the presence of high contents of kaolinite, feldspar, quartz and other essential minerals present in the composition (Pereira, 2000).Releasing of the earthworm into the soil for decomposition is best done when the temperature is near 25°C (Nagavallemma*et al.* (2006)). At this temperature, the atmosphere is humid, and conducive for the activities of the earthworm thereby facilitating the breaking down and degradation process.

## 3. HARMFUL COMPONENTSOFCONTAMINATED SOILS

Soil contamination is a global problem that constitutes significant threat to human and environmental health both in the present and in the future. Soil contamination has been an important topic in many areas of research, practice and policy within different countries which has also been extended internationally (Troeh, Hobbs, & Donahue, 1981). The attached importance to contaminated soil has been increasing over the years. Increased population growth and industrialization around the world are key factors responsible for the increase in the contamination of soil and the environment which negatively affects various human health, wildlife, and microorganisms. The contaminant sources are waste disposal sites, mining sites, crude oil refineries and exploration, chemical application in agriculture, use of wastes water for irrigation, industrial emissions and maintenance (Zhan, et al., 2013).

Contaminant can be any element that has the potential of causing harm on the environment. Environmental contamination is primarily interested in the physical, chemical or biological agents or their combinations that may pose a threat to life, health, safety or welfare of organisms in the environment. Soil contamination is the existence of these contamination above permissible limits at which deterioration or loss of soil functions occur (Cottenie & Verloo , 1984). Major areas of soil contamination and pollution have been highlighted by Blum (1990) as follows:

- Radioactive pollution of the soil. Accidental release of radioactive substances has been discovered in some part of the world. The substances are very harmful to the soil and provide an unsafe environment for human life and living organisms. There is currently serious concern over the risk of soil pollution on food safety and the sustainability of agricultural production across the globe. Fears of the food chain being compromised by soil pollutants are eminent as the consumption of food crops contained with pollutants remained a major suspect in food poison. Several studies have linked serious human health challenges to heavy metal accumulation by plants from contaminated soils (Lente , Keraita , Drechsel, Ofosu-Anim, & Brimah, 2012; Muchuweti, et al., 2006; Khan , Cao, Zheng, Huang, & Zhu, 2008; Zhuang , McBride, Xia, Li, & Li, 2009)
- Soil acidification through the accumulation of acid from phosphate fertilizer, carbon, nitrogen and Sulphur cycles, and acid rains. Soil acidification lowers the soil pH and alters the soil chemistry. When the soil pH is reduced, the bioavailability of heavy metals in the soil is increased and a harmful environment for biological activities is created, the breakdown of nutrients for plant uptake is also hindered and the food chain compromised.
- Direct introduction of toxic elements and compounds such as petroleum hydrocarbon and other dangerous organic compounds. This contributes to making the soil unsafe and creates an impediment in its functions.

Petroleum hydrocarbon is a complex substance formed from hydrogen and carbon molecules and sometimes containing other impurities such as oxygen, Sulphur, and nitrogen, heavy metals and oxygen compounds. Examples of petroleum hydrocarbon contaminants are total petroleum hydrocarbons (TPHs) and Polycyclic aromatic hydrocarbons (PAHs). Soil contamination with petroleum hydrocarbons is one of the adverse environmental problems associated with crude oil exploration in any part of the globe. Natural gas, Crude oil, tars and asphalt are types of petroleum hydrocarbons (Frick, Farrell, & Germida, 1999).

Total petroleum hydrocarbons (TPHs) are used to describe mixture of organic compounds found in or derived from crude oil that has the potential to be very toxic (CCME, 2001). Total petroleum hydrocarbons can generally be divided into three fractions: (i) aliphatic, (ii) aromatics and (iii) polar and asphaltenes(Kang, Park, Jung, & Park, 2009). When soil is contaminated by petroleum hydrocarbons, the soil will have insufficient aeration due to the displacement of air from the spaces or pores between the soil particles. The displacement of air in the soil pores by petroleum hydrocarbons will cause anaerobic environment in soil by smothering soil particles and blocking air diffusion in the soil pores and affect the soil microbial communities negatively (Townsend, Prince, & Suflita , 2003; Labud , Garcia, & Hernandez , 2007; Sutton , et al., 2013)


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Most product that contain total petroleum hydrocarbons (TPHs) are naturally volatile. Some are clear or light colour liquids that evaporate easily and others, arethick, dark liquids or semi–solid that do not evaporate and many of these products (gasoline, kerosene, etc.) have oily odours (Giller, Witter, & McGrath, 1998). The composition of petroleum hydrocarbons (PHCs); varies slightly by its source, but the toxic properties are consistent. Chemicals such as benzene and polycyclic aromatic hydrocarbons (PAHs) are extremely toxic components of serious concern (Kamath , Rentz, Schnoor, & Alvarez, 2004).

Table 1: Percentage of elements and hydrocarbons present in the crude oil (Hyne, 2012)

| Major components of crude oil | | Hydrocarbons present in crude oil | | |
|---|---|---|---|---|
| Element | Weight (%) | Hydrocarbons | Weight (%) | Range |
| Carbon | 84-87 | Alkanes (Paraffins) | 30 | 15-60 |
| Hydrogen | 11-14 | Naphthenes | 49 | 30-60 |
| Nitrogen | 0.1-2.0 | Aromatics | 15 | 3-30 |
| Oxygen | 0.1-2.0 | Asphaltic | 6 | Remainder |
| Sulfur | 0.06-2.0 | | | |

Source: (Hyne, 2012)

## 4. UTILIZATION OF VERMICOMPOSTING IN CONTAMINATED SOILREMEDIATION

Humidified adsorbent have been adopted for the immobilization of soil contaminants such as heavy metals. The remediation of polluted soils using vermicompost processes depend on several factors such as the particle size of the soil, the structural characteristics of the clay present in the soil, the quantity and quality of the humic segment of the vermicompost, the chemical and the physical properties of the pollutants to be degraded (Pereira *et al.,* 2014). These qualities aid in decreasing the level and mobility of the dangerous chemicals present in the polluted soils.

Delgado–Moreno and Pena (2009) adopted vermicomposting process for the reduction of the herbicide [3–(3,4–dichlorophenyl)–1,1–dimethylurea, or diuron] in soils. Thediuron ($C_9H_{10}Cl_2N_2O$) exhibits reasonable polarity, thus there was considerable affinity between this compound and the hydrophilic groups of the vermicompost, with the consequent distribution of diuron through different horizons of amended soils. The vermicompost used by Delgado–Moreno and Pena (2009) was derived from olive cake to the herbicide contaminated soil. The calcareous soil was mixed with vermicompost and other substrates at rates four times higher than the agronomic recommended dose. Observation showed that the biological degradation of the herbicides increased during the first week of incubation, but residual concentrations of all herbicides (simazine, terbuthylazine, cyanazine, and prometryn) were similar between the non–treated and treaed soils. Owing to this, vermicompost increased the kinetics of herbicide decomposition (by means of microbial biostimulation), but it did not act on the thermodynamic aspect.

Similarly, Fernandez–Bayo*et al.* (2007) studied the effect of vermicompost on imidacloprid ($C_9H_{10}ClN_5O_2$) insecticide mobility of many Spanish soils. The vermicompost successfully reduced and degraded the imidacloprid releasing the polluted substance. As expected from considerations of polarity, vermicompost was responsible for substantial retention of imidacloprid, as observed for diuron (Delgado–Moreno and Pena, 2009).Kadian et al., (2012) in their study detected that the concentrations of different pesticides decreased in the soil after being treated with vermicompost. The microorganism stimulating ability of the vermicompost was the main cause of the pesticide decomposition. The study by Iwamoto and Nasu(2001) showed that the in order to establish bioremediation in soils, one of the important criteria to consider is the organic amendment ability of the biostimulating microorganisms to be used for the remediation process.

Alvarez–Bernal *et al.*(2006) removed Polycyclic Aromatic Hydrocarbons (PAHs) using vermicompost although the consequence of the experiment was high residual of phenanthrene, anthracene and benzo(a)pyrene present in the soil. In a study by Contreras–Ramos *et al.* (2008), earthworms and biosolids were employed, in the extraction of Polycyclic Aromatic Hydrocarbons (PAHs) from polluted soils. The vermicompost showed low effectiveness in the remediation process which could be attributed to the weak polarity of PAHs. This tends to nullify the thermodynamic tendency of transferring these organic pollutants to the vermicompost (Pereira *et al.,* 2014).

Jordao et al. (2011)in their study to minimize the heavy metalssoil pollution, added vermicompost to tropical soils in order to decrease the mobility of $Cd^{2+}$ and $Cu^{2+}$. The authors achieved satisfactory results, which was as a result of the accentuated spontaneity related to adsorptive processes ($\Delta G$ around – 14,000 $kJmol^{-1}$). Their work also showed that vermicompost is able to bioremediate metallic contaminated soils containingand this ability is also extended to other organic substrates (Kavamura and Esposito, 2010). According to Park et al. (2011), bioremediation of metals by organic substrates is as a result of the immobilization, reduction, volatilization, and modification of the rhizosphere.


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Furthermore, vermicompostretain ionic species through adsorptive mechanism in terms of immobilization. This mechanism aid the process in the bioremediation of heavy metals such as $Cd^{2+}$ and $Cu^{2+}$ as studied by Jordao et al. (2011). Vermicompost also remediates the soil through reduction process as it serves as a source of electron and carbon for reducing microorganisms (Pereira *et al.*, 2014). Also remediation of heavy metal contaminated soils through volatilization process can also be carried out using vermicompost due to the microbiological methylation of some group of elements which include Se, As and Hg. The microorganisms present in the vermicompost play essential role in the methylation and reduction reactions and thus provides substantial microbiota to the soil which stimulates the microbial population of the soil. (Park et al. (2011).

Vermicompost cannot only be considered as a source of microorganisms to soils but also as a supply of nutrients for the native microbiota of these ecosystems. Studies have showed that soils polluted with different herbicides (Delgado–Moreno and Pena, 2009, Fernandez–Bayo*et al.*, 2009) had their microbial populations restored after the addition of vermicompost. In these specific cases, the greater part of the microbiota from the vermicompost was fixed to the soil (Pereira *et al.*, 2014).Vermicompostsand diverse other organic amendments release weak acids (citric, maleic, lactic, oxalic, propanoic, and butyric acids, among others) to soils. This reduction in soil pH has profound consequences on the chemistry and biology of these ecosystems, especially in the rhizosphere that comprises the area immediately around the roots (Kavamura and Esposito, 2010). In this case, bioremediation is improved by excess of $H_3O^+$ in soil solution which stimulates the transfer of metallic pollutants to plants. This situation is clearly desirable only for plants devoted to removal of hazardous metals from polluted soils.

Table 2: Summary of vermicomposting of contaminated soils

| S/No | Waste type/ composition | Earthworm used | Vermicomposting duration (days) | Result | Reference |
|---|---|---|---|---|---|
| 1. | Crude Oil | Earthworms (*Eudrilluseuginae*and *Lumbricusterrestris*) | 30 | Activities of *E. euginae*led to 88.50% TPH loss, *L. terrestris*led to 76.42% loss while combined activities of the two earthworms led to 73.06% loss of TPH from the soil contaminated with 3ml crude oil after 30days. | Njoku, Nomba, and Olatunde, (2017) |
| 2. | Municipal sewage sludge digestate | *Eiseniafetida* | 60 | Lower content of vinasse and higher content of zeolite resulted in better quality compost. | Alavi et al. 2017 |
| 3 | Asphaltenes from Heavy fuel oil | *Eiseniafetida* | 183 | Microorganisms obtained carbon and energy from asphaltenes. | Martín–Gil et al. 2008 |
| 4. | Municipal solid waste, grass clippings, sawdust | *Eiseniaandrei, Eiseniafetida, Dendrobaenaveneta* | 45 | Eisenia species of earthworms exhibited stronger defence and higher ability to accumulate heavy metals. | Suleiman et al. 2017 |
| 5 | Cow dung, green manure plants | *Eudriluseugeniae* | 50 | Ratio 2:1:1 (pressmud: cow dung: green manure plants) resulted in the high quality compost. | Balachandar et al. 2020 |
| 6 | Cattle manure, spent mushroom substrate | *Eiseniafetida* | 70 | Ratio 2:1:1 (garden waste: cattle manure: spent mushroom substrate) resulted in high quality compost. | Gong et al. 2019 |
| 7 | Corn waste, cow dung, compost, paper | *Eiseniafetida* | 40 | Increase in heavy metal content due to the decrease in overall mass. | Kharrazi et al. 2014 |
| 8. | Petroleum hydrocarbons | *Eiseniafetida* | 15 | Enrichment of microorganisms after adding compost as an amendment. | Ceccanti et al. 2006 |
| 9. | Pig manure | *Eiseniafetida* | 45 | Increase in the Cu and Zn availability after | Zhu et al. 2014 |
| 10. | Rice straw, paper waste | *Eiseniafetida* | 105 | High fragmentation and homogeneity of vermicompost based on SEM pictures. | Sharma and Garg 2018 |
| 11 | Sugarcane press mud | *Drawidawillsi* | 40 | Composting–vermicomposting method reduced the time required for composting. | Kumar et al. 2010 |
| 12 | Anthracene, phenanthrene, benzo(a)pyrene | *Lumbricusrubellus* | 60 | 99.99% PAHs removed. | Azizi et al.2013 |
| 13. | 16 priority PAHs | *EiseniaAndrei* | 35 | Degradation of 5–ring PAHs to 3– and 4–ring PAHs is reported. | Rorat et al. 2017 |
| 14 | Sewage sludge, vinasse | *Eiseniafetida* | 56 | Rabbit manure enhanced the reproduction and weight of earthworms. | Molina et al. 2013 |
| 15 | Municipal solid waste, grass clippings, sawdust | *Eiseniaandrei, Eiseniafetida, Dendrobaenaveneta* | 45 | Eisenia species of earthworms exhibited stronger defence and higher ability to accumulate heavy metals. | Suleiman et al. 2017 |
| 16 | Vegetable waste | *Eiseniafetida, Eudriluseugeniae* | 20 | Stabilized end product within a short period of time using rotary drum | Varma and Kalamdhad 2016 |


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## 5. CONCLUSION

Microorganisms are known to be responsible for biochemical degradation of waste matter, but vermicomposting is essentially influenced by the physical and biochemical activities of earthworms, whose line of action is to ingest the waste matter thereby creating a high quality compost resulting in a rich material with essential elements for plants. Vermicomposting have been beneficial in decontaminating aqueous media by adsorbing or degrading pollutants, increasing soil fertility and agricultural productivity and promoting the biocontrol of agricultural disease. Vermicomposting has been successfully used for removing polycyclic aromatic hydrocarbons, organic wastes and heavy metals. This mini–review indicates that vermicomposting is a promising low–cost and environmentally friendly way of treating contaminated soils.

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